



National Aeronautics and
Space Administration



Space Technology Mission Directorate

ADVANCED PROPULSION STRATEGIC TECHNOLOGY PLAN

INNOVATION & OPPORTUNITY CONFERENCE 2020

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NASA/STMD | HQ

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www.nasa.gov/spacetech



STMD STRATEGIC FRAMEWORK

A Data Driven Space Technology Investment Portfolio



STMD Strategic Framework

LEAD



Ensuring American Global Leadership in Space Technology

- Lunar exploration building to Mars & new discoveries at extreme locations
- Robust national space technology engine to meet national needs
- U.S. economic growth for space industry
- Expanded commercial enterprise in space

Note: Multiple technologies are cross cutting and support multiple thrusts. Primary emphasis is shown.

THRUSTS



Go Rapid, Safe, & Efficient Space Transportation

- Advanced Propulsion
- Cryogenic Fluid Management



Land Expanded Access to Diverse Surface Destinations

- Human & Robotic Entry, Descent and Landing
- Precision Landing



Live Sustainable Living and Working Farther from Earth

- Advanced Human Life Support Systems
- Advanced Materials, Structures & Manufacturing
- Advanced Power
- In-situ Propellant & Consumable Production
- Autonomous Systems & Robotics



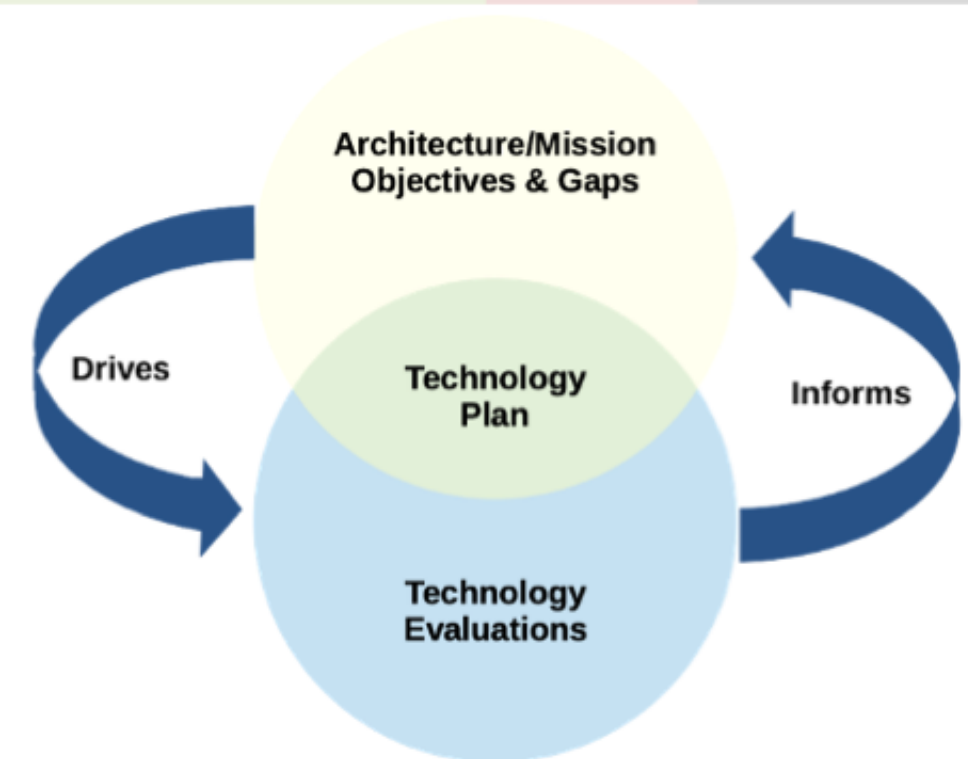
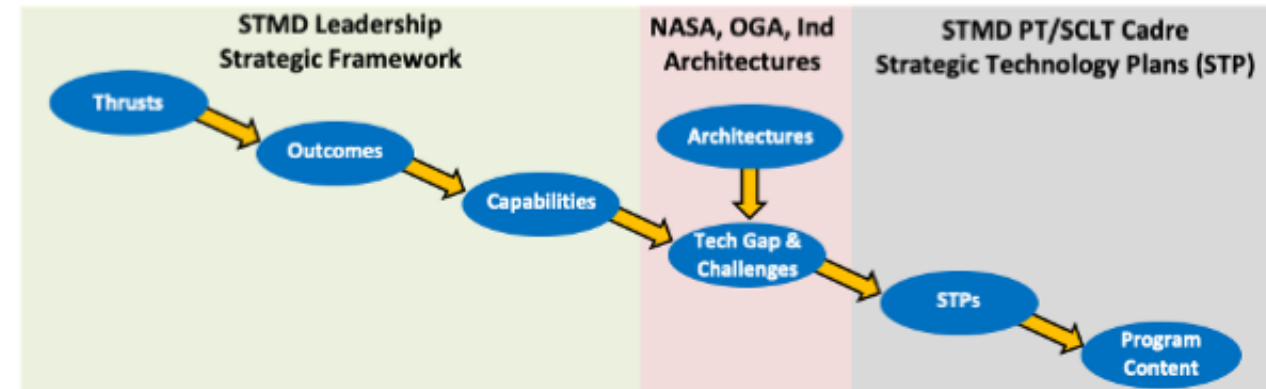
Explore Transformative Missions and Discoveries

- On-Orbit Servicing, Assembly & Manufacturing
- Advanced Avionics
- Advanced Communications and Navigation
- Extreme Access
- Small Spacecraft Technologies

SPACE TECHNOLOGIES



Space Technology Portfolio Formulation





GO THRUST

Overarching Strategic Goals



STRATEGIC FRAMEWORK

STRATEGIC THRUSTS

Vision for Future

OUTCOMES

Overarching Goals

CAPABILITIES

Measurable Results

STP

Programmatic Content

Architectures
Tech Gaps

Space Access

In-Space Transportation

2020s

- Multiple Highly-Reusable Commercial Launch Services (CLV) Fleets Supporting Space Science, Exploration, Commerce, and Security
- Multiple Affordable, Dedicated, Responsive Small Launcher Services Fleets for Orbital Delivery of Next Generation Small Spacecraft Platforms
- Development of Alternative High-Speed Propulsion Technologies and Integrated Space Access Concepts

- Introduction of Compact, Reduced-Cost Cold Tolerant In-Space Storable Propulsion Systems for Long-Duration, Extreme Environments Operation
- Accelerated Adoption & Deployment of Reduced-Cost Advanced Manufactured In-Space Cryogenic Liquid Propulsion Systems
- Flight Demonstration and Introduction of Mid-Range-Power EP System (7-14 kW Strings) Serving Exploration, Science, Commerce and Security Needs
- Introduction of Rad-Tolerant, High ΔV , Sub-kW EP Systems Enabling Small S/C Deep Space Missions
- Development & Flight Demonstration of Space Nuclear Propulsion (SNP) Systems (NTP &/or NEP) Establishing Viability, Feasibility, and Affordability
- Sustained Research and Initial Proof-of-Principle Demonstrations of Advanced Energetic Propulsion Technologies to Enable Ambitious Missions Throughout the Solar System & Beyond

2030s

- CLV Launch Costs Reduced by Order of Magnitude Supporting Increased Mission Utility & Market Growth
- Dedicated, Responsive Small Spacecraft Space Access Costs Reduced by 50% Supporting Increased Mission Utility & Market Growth
- Demonstration of Alternative High-Speed Propulsion Systems and Integrated Space Access Concepts

- Widespread Adoption and Infusion of Green Propellant Propulsion Systems & Introduction of Rotating Detonation Rocket Engines
- In-Space Cryogenic Liquid Propulsion Costs & Reusability Improved by an Order of Magnitude Promoting Mission Utility & Market Growth
- Flight Demonstration and Introduction of High-Power EP System (50-100 kW Strings) Serving Exploration, Science, Commerce and Security Needs
- Sub-kW EP Propulsion Costs and Lifetime Improved by an Order of Magnitude Promoting Mission Utility
- Flight Certified SNP Systems (NTP &/or NEP) Supporting Fast Opposition-Class Human Expedition to Mars & Outer Solar System kWe-Class Science
- Initial Ground Demonstration of Advanced Energetic Propulsion Technologies to Enable Short Trip Time Interplanetary Missions Throughout the Solar System & Interstellar Flight

2040s

- Robust Commercially-Sustained Up/Down Transportation Market Underpinning a Vibrant and Dynamic Space Economy
- Establish Routine Commercially-Sustained Airport-Like Launch Operations with Broad Based User Community
- Introduction of Integrated High-Speed Propulsion Space Access Systems to CLV Fleets

- Thrust Scale-Up of Green Propellant Propulsion Systems, Rotating Detonation Rocket Engines, and Advanced Storable Propulsion Systems
- Robust, Highly Reusable Liquid Propulsion Systems Supporting ISRU-Sustained Cis-Lunar/Mars Commercial Fleets
- Introduction of Very-High-Power EP Systems (100 – 1000 kW strings) Enabling Efficient & Rapid Cis-Lunar/Mars Transportation of Cargo & Crew
- Widespread Adoption of Sub-kW EP Platforms with Revolutionary Impacts on Mission Capability/Cost
- Robust and Reusable SNP Transportation Systems Supporting Cis-Lunar/Mars Blue Water Mobility and Sustained Mars Exploration
- Initial Breakthrough Flight Demonstration of Advanced Energetic Propulsion Technologies to Enable Short Trip Time Interplanetary Missions and Interstellar Flight



ADVANCED PROPULSION STP

Content & Propulsion Technology Apportionment



STP – Table of Contents

- Definition & Scope of Technology Domain
- Architecture Drivers
 - Technology Gaps & Challenges
 - Quantifiable Capability Outcomes
- Structured Technology Maturation & Closure Plans
- Transformational Technology Push
- Industry, DOD & OGA Data (Limited Distribution)



Apportionment of Space Propulsion Technologies across STPs*

STP	TX-1 Propulsion Systems				TX-9 EDL
	1.1 Chemical Space Propulsion	1.2 Electric Space Propulsion	1.3 Airbreathing Propulsion	1.4 Advanced Propulsion	9.3 Landing Propulsion
Advanced Propulsion	<ul style="list-style-type: none">• Storable• Solid• Hybrid	<ul style="list-style-type: none">• Electrostatic• Electromagnetic• Electrothermal	<ul style="list-style-type: none">• Space Access TBCC• Space Access RBCC	<ul style="list-style-type: none">• Sails/Tethers• NTP/NEP• All Other	<ul style="list-style-type: none">• Storable• Solid• Hybrid
CFM	<ul style="list-style-type: none">• Cryogenics Technologies• Integrated CFM Systems	N/A	<ul style="list-style-type: none">• Cryogenics Technologies• Integrated CFM Systems	<ul style="list-style-type: none">• Cryogenics Technologies• Integrated CFM Systems	<ul style="list-style-type: none">• Cryogenics Technologies• Integrated CFM Systems
AMSM	<ul style="list-style-type: none">• Materials & Structures• AM Components	<ul style="list-style-type: none">• Materials & Structures• AM Components	<ul style="list-style-type: none">• Materials & Structures• AM Components	<ul style="list-style-type: none">• Materials & Structures• AM Components	<ul style="list-style-type: none">• Materials & Structures• AM Components
SST	<ul style="list-style-type: none">• Sub-Newton CP	<ul style="list-style-type: none">• Sub-kW EP	N/A	<ul style="list-style-type: none">• SST Sails/Tethers	<ul style="list-style-type: none">• Small Lander Craft

* Based on 2020 NASA Technology Taxonomy

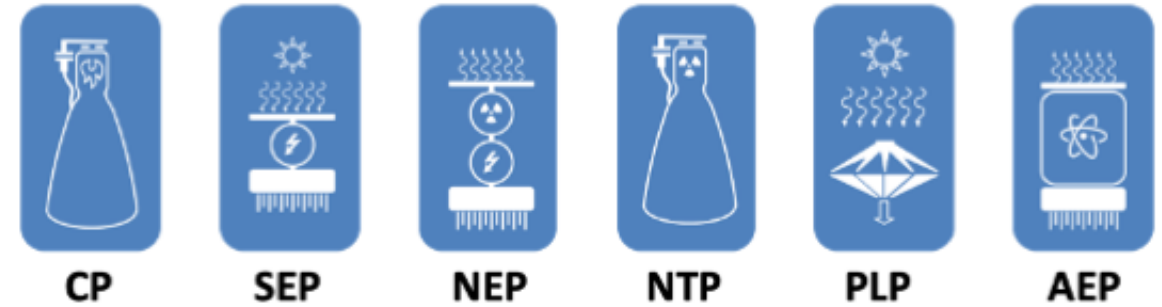


ADVANCED PROPULSION DEFINITION & SCOPE

Space Transportation Triad & Advanced Propulsion Technologies



PROPULSION TECHNOLOGY TAXONOMY



CP – Chemical Propulsion

SEP – Solar Electric Propulsion

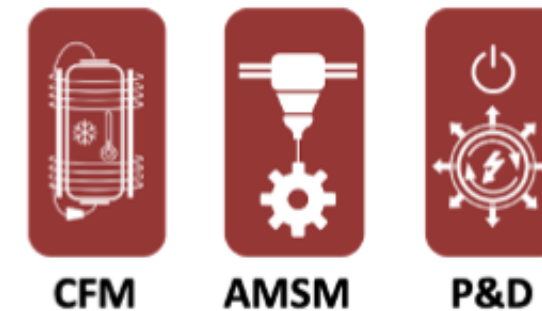
NEP – Nuclear Electric Propulsion

NTP – Nuclear Thermal Propulsion

PLP – Propellant-Less Propulsion

AEP – Advanced Energetic Propulsion

CROSS-CUTTING SUPPORT TECHNOLOGIES



CFM – Cryogenic Fluid Management

AMSM – Advanced Materials, Structures, & Manufacturing

P&D – Power & Distribution



SPACE FLIGHT DOMAINS

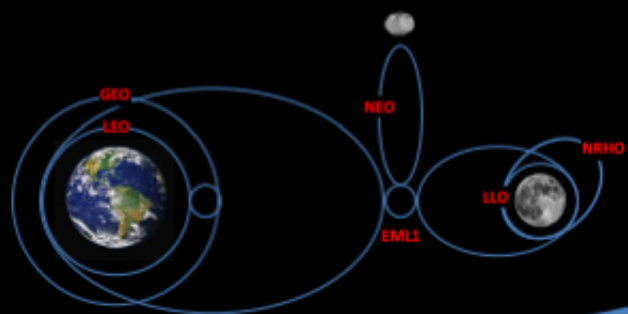
Science, Exploration, Commerce & Security

CIS-LUNAR

CLPS/ARTEMIS & Cis-LUNAR DEVELOPMENT

- ❖ Science Payloads
- ❖ Mining & Resource Extraction
- ❖ Manufacturing
- ❖ Fuel Depots
- ❖ Space Solar Power
- ❖ Outposts (In-Space & Surface)
- ❖ Tourism
- ❖ Rule of Law Compliance
- ❖ Planetary Defense Assets
- ❖ Space National Security Assets

"Commercially Sustained Cis-Lunar Infrastructure"
 $\Delta v < 5 \text{ km/s}$



CP | SEP | NTP | NEP

"Littoral & Blue Water Mobility Analog"

MESO-SOLAR

MOON-TO-MARS & EXPANDING SCIENCE/EXPLORATION

- ❖ Humans on Mars
- ❖ Search for Life
- ❖ Sample Return
- ❖ Outer Planetary Science
- ❖ Resource Mapping
- ❖ Asteroid Prospecting

Mars
1.5 AU



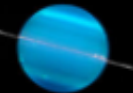
Jupiter
5.2 AU



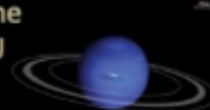
Saturn
9.5 AU



Uranus
19 AU



Neptune
30 AU



Pluto
40 AU



Advanced Energetic Propulsion Processes & Concepts
"Rapid & Efficient Deep Space Transit"

EXTRA-SOLAR

OUTER SOLAR SYSTEM & INTERSTELLAR

- ❖ KBOs & Primitive Bodies >50 AU
- ❖ Heliosphere / Local ISM 100-200 AU
- ❖ Pristine ISM 200-400 AU
- ❖ Solar Gravity Lens 500-800 AU
- ❖ Nearby Stars / Exoplanets 4.5-20 LY

PROPULSION TECHNOLOGY TAXONOMY



CP

CP – Chemical Propulsion



SEP

SEP – Solar Electric Propulsion



NEP

NEP – Nuclear Electric Propulsion



NTP

NTP – Nuclear Thermal Propulsion



PLP

PLP – Propellant-Less Propulsion



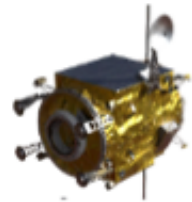
AEP

AEP – Advanced Energetic Propulsion



EXPLORATION ARCHITECTURE DRIVERS

Lunar Phase



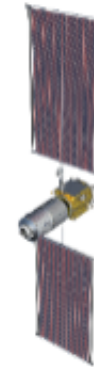
PPE

- 1st Gateway Element
- PPP – Maxar Tech
- 50kW-Class SEP
 - AEPS Infusion
 - 12.5-kW HET Strings
 - 2000-kg Xe Capacity
- Multi-Phase Demo
 - Launch, Deploy, Checkout
 - SEP Orbit Transfer
 - NRHO Demo
 - Handover



CLPS

- Commercial Lunar Payload Services
- Multiple Qualified Providers (14)
- Initial Mission Selections
 - Astrobotic - 2021
 - Peregrine (MON-25/MMH)
 - Intuitive Machines - 2021
 - Nova-C (LOX/CH4)
 - Masten - 2022
 - XL-1 (MXP-351 - Proprietary)
 - Astrobotic - 2023
 - Griffin (MON-3/M20)



Foundational Gateway



Artemis Commercial Crew & Cargo Lunar Surface Access Systems

- Artemis HLS Crew/Cargo Services
- HLS Development Selections
 - SpaceX
 - Starship (LOX/CH4)
 - Blue Origin – National Team
 - Transfer – NG (LOX/H2)
 - Lander – BO (LOX/H2)
 - Ascent – LM (OMS-E Storable)
 - Dynetics
 - Modular Propellant Vehicles (LOX/CH4)
 - ALPACA

ISS/LEO Testing | Foundational Gateway Operations | Lunar Surface Precursors

Lunar Surface Human Return





EXPLORATION ARCHITECTURE DRIVERS

Mars Phase



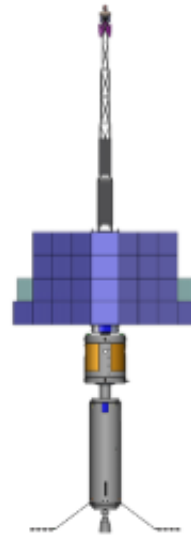
Mars Transport Options

- NEP/CP Hybrid – Current Reference Configuration

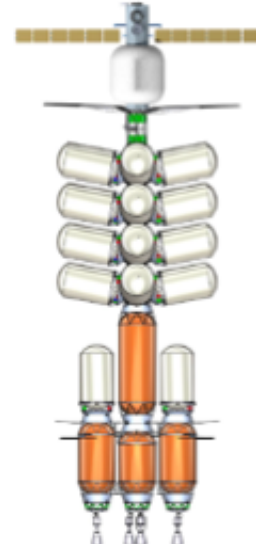
- High Thrust CP – Gravity Well ΔV
- Multi-MW NEP – Cruise ΔV
- LOX/LCH₄ Storage/X-Fer
- Opposition-Class Capability

- NTP – Alternate

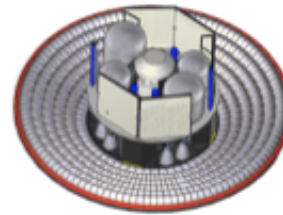
- High Thrust NTP – Gravity Well ΔV
- Reactor Integrated OMS – Supplemental ΔV
- LH₂ Storage/X-Fer
- Opposition-Class Capability



NEP/CP



NTP



Mars EDL

- Lander Delivery



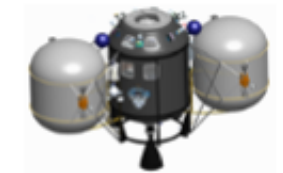
MAV Propellant Storage Lander

- LOX/CH₄ Propulsion



Mars Ascent Stage

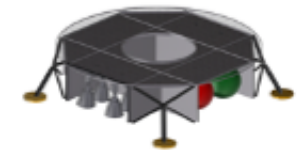
- LOX/CH₄ Propulsion



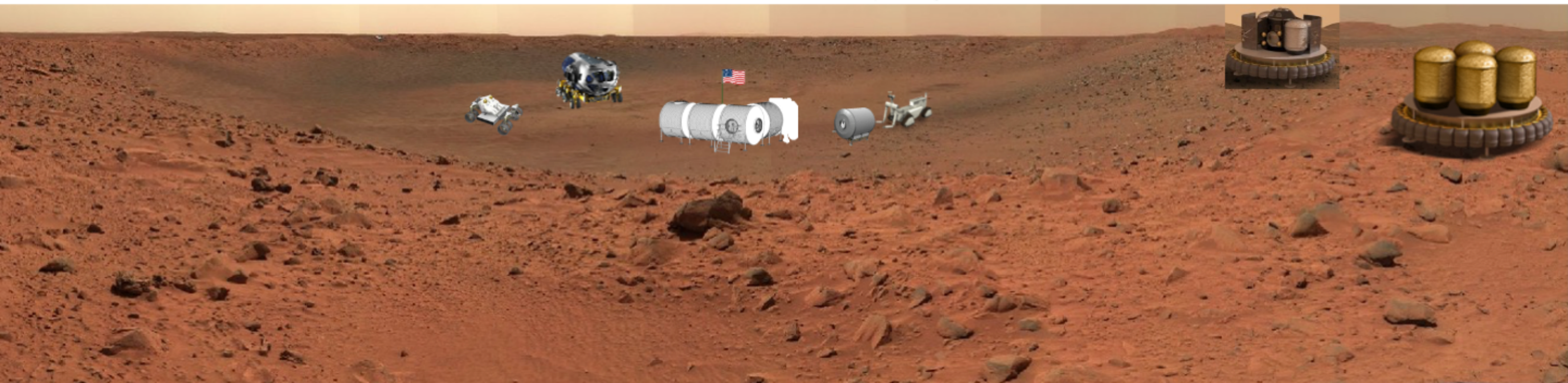
2nd stage



1st stage



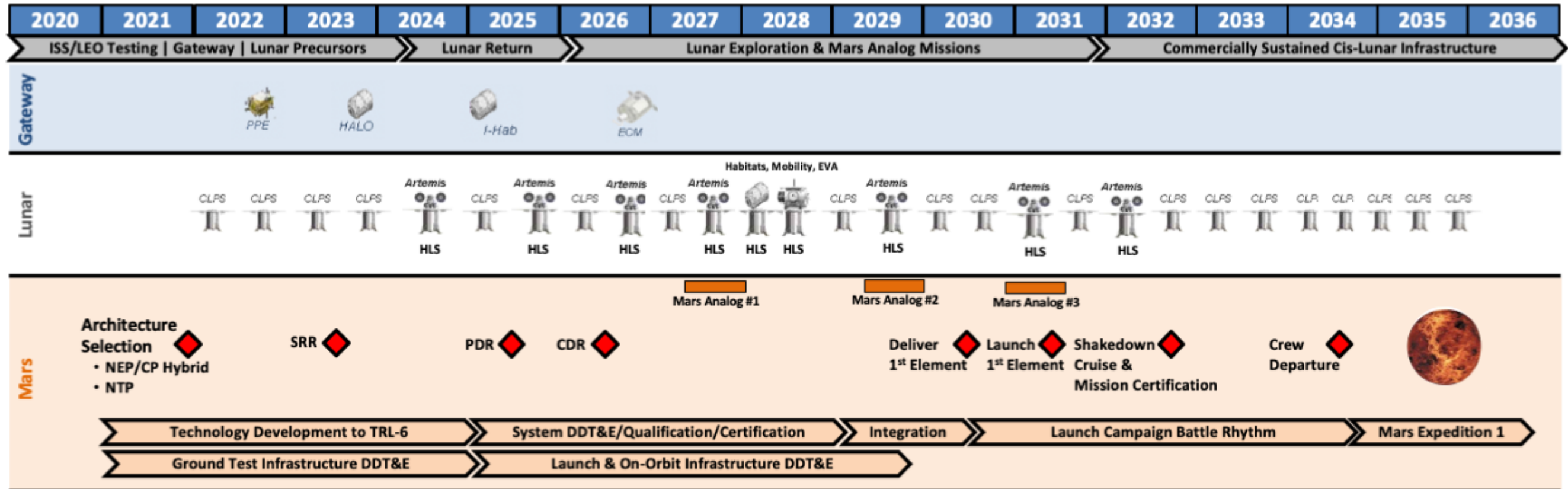
Mars Descent Module





EXPLORATION ARCHITECTURE DRIVERS

Moon-to-Mars Campaign – Transportation Architectures & Elements



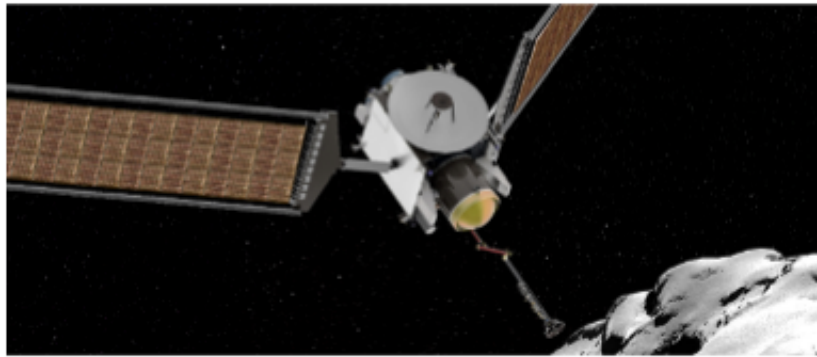
MTAS Programmatic Assumptions*

- Component/Subsystem TRL-6 @ Element PDR
- System-Level Ground Test Infrastructure 80% Complete @ Element PDR
- Element PDR Occurs at Least 5-years Prior to 1st Element Launch
- Critical Systems TRL-6 @ Element CDR
- Element Delivered to Range 1-year Prior to Launch

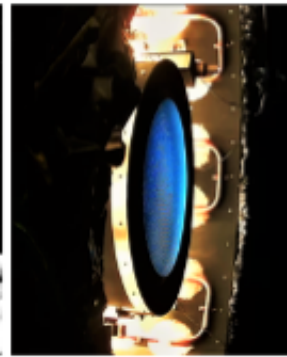
* Vetted by MTAS Programmatic Team

SCIENCE, COMMERCE & SECURITY ARCHITECTURE DRIVERS

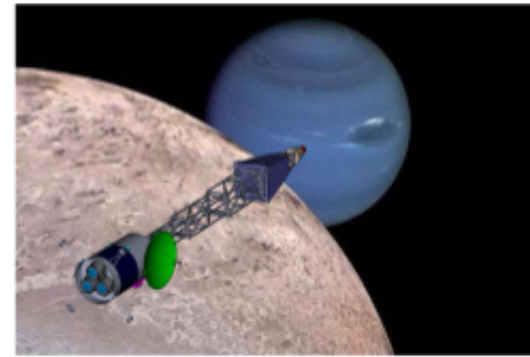
Enhanced Spacecraft/Platform Mobility



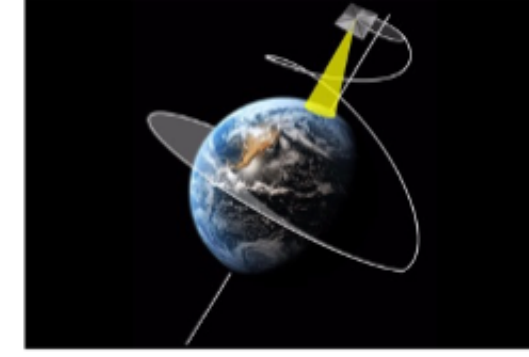
High- ΔV EP Robotic Spacecraft



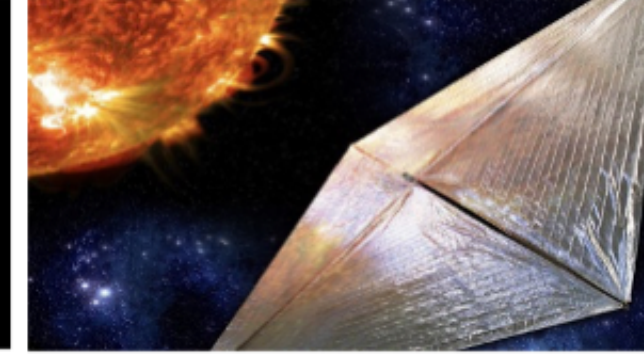
NEXT-C



10-kWe NEP Neptune-Triton Spacecraft



Earth Pole-Sitting Satellite



Sun Pole Observer Satellite

Deep Space Science, Commercial & Security Missions Requiring Very High- ΔV EP Capability Beyond NSTAR

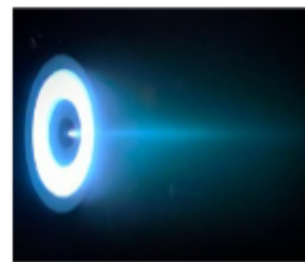
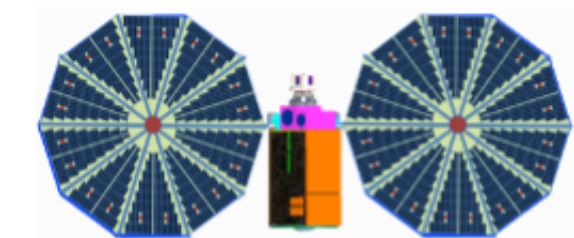
- NEXT-C Xenon Ion Engine
 - Enable Highly Challenging New SEP/NEP Robotic Missions
 - Extend Power, Thrust, Isp, & Xenon Throughput beyond NSTAR
 - Second String NEXT-C Engineering Closeout & Build
 - Demonstrate Full Capabilities & Flight Qualification

Outer Solar System Science Requiring NEP Capability

- KiloPower Derived 10-kWe NEP
 - Enable High- ΔV Missions Beyond SEP
 - Abundant Deep Space S/C Power
 - Improved SWaP, COMM & Trip Time
 - Leverage Fission Surface Power Dev

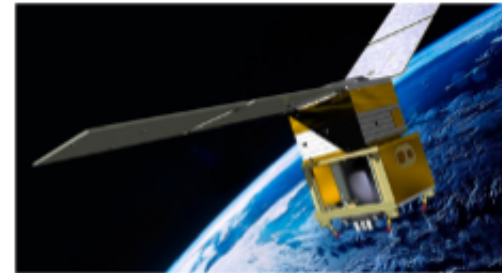
Observational Platforms for Science, Commercial & Security Missions Requiring Unlimited ΔV Capability

- Solar Sail Development & Demonstration (e.g., Solar Cruiser)
 - Artificial Equilibria & Indefinite Station Keeping along or offset the SEL
 - Lagrange Point Station Keeping
 - Change Heliocentric Inclination from Ecliptic to Solar Polar
 - Functionally Equivalent Geostationary Earth Orbits



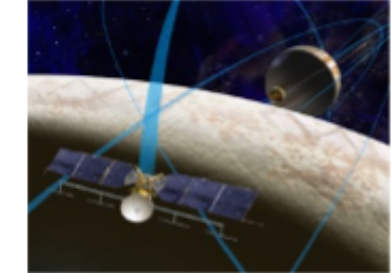
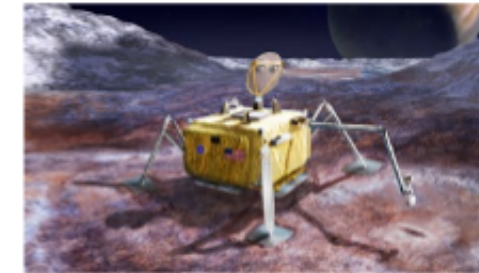
Small Spacecraft Science, Commercial & Security Missions Requiring High ΔV Capability

- Sub-kW Electric Thrusters
 - Enable High- ΔV SPA-Class S/C Missions
 - Fully Qualify High-Throughput, Rad-Tolerant Capability



Green Propellant Adoption & Infusion into Missions of Opportunity

- Overcome Infusion & Transition Challenges
 - Incentivize Mission Adoption
 - PPP to Mature a Wide Range of Thrust Classes



Deep Space Science Missions Requiring Cold Tolerant Storable Propulsion for Extreme Environments Access

- MON-25/MMH Bipropellant Thruster Technology
 - Outer Planetary Body Surface Access – Europa Lander
 - Extensible Total Impulse – Long Burn Deep Space Orbit Transfer



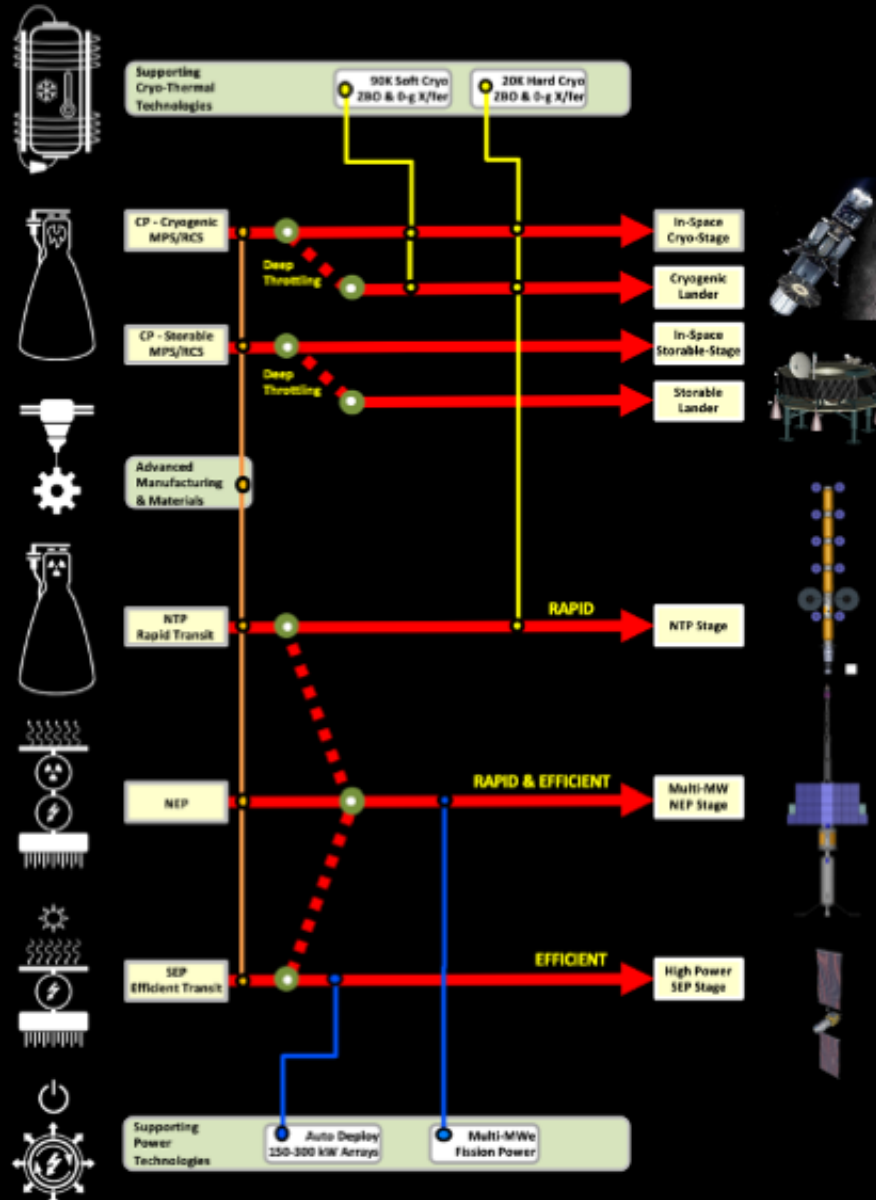
TRANSFORMATIONAL & INNOVATION DRIVEN R&T

Portfolio Diversification & Balance



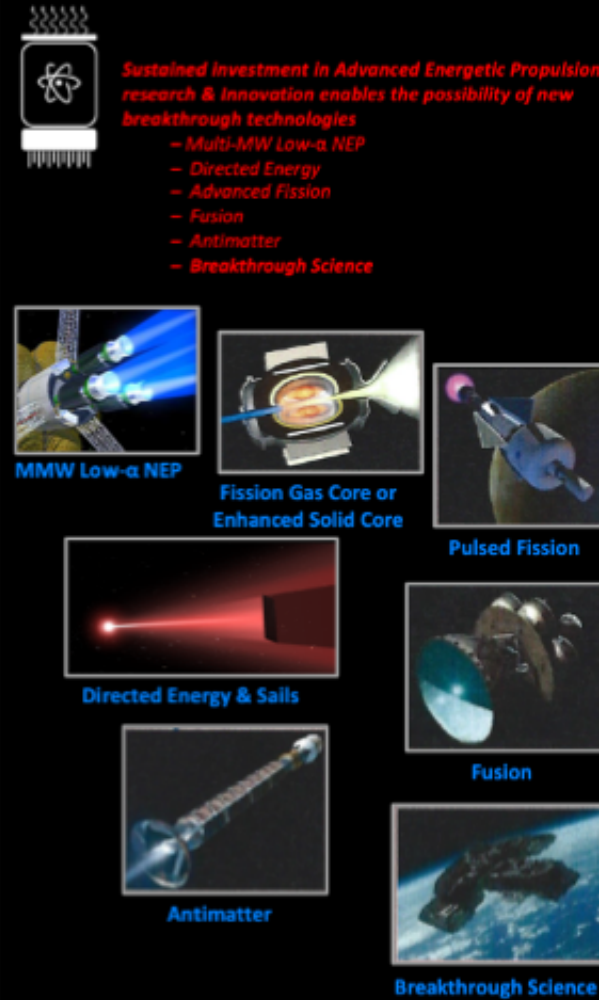
ARCHITECTURE DRIVEN TECHNOLOGY CLPS/ARTEMIS/CIS-LUNAR/MOON-TO-MARS

PROPULSION TECHNOLOGIES → SYSTEMS



INNOVATION DRIVEN RESEARCH OUTER SOLAR SYSTEM & INTERSTELLAR

OUTER SOLAR SYSTEM & INTERSTELLAR



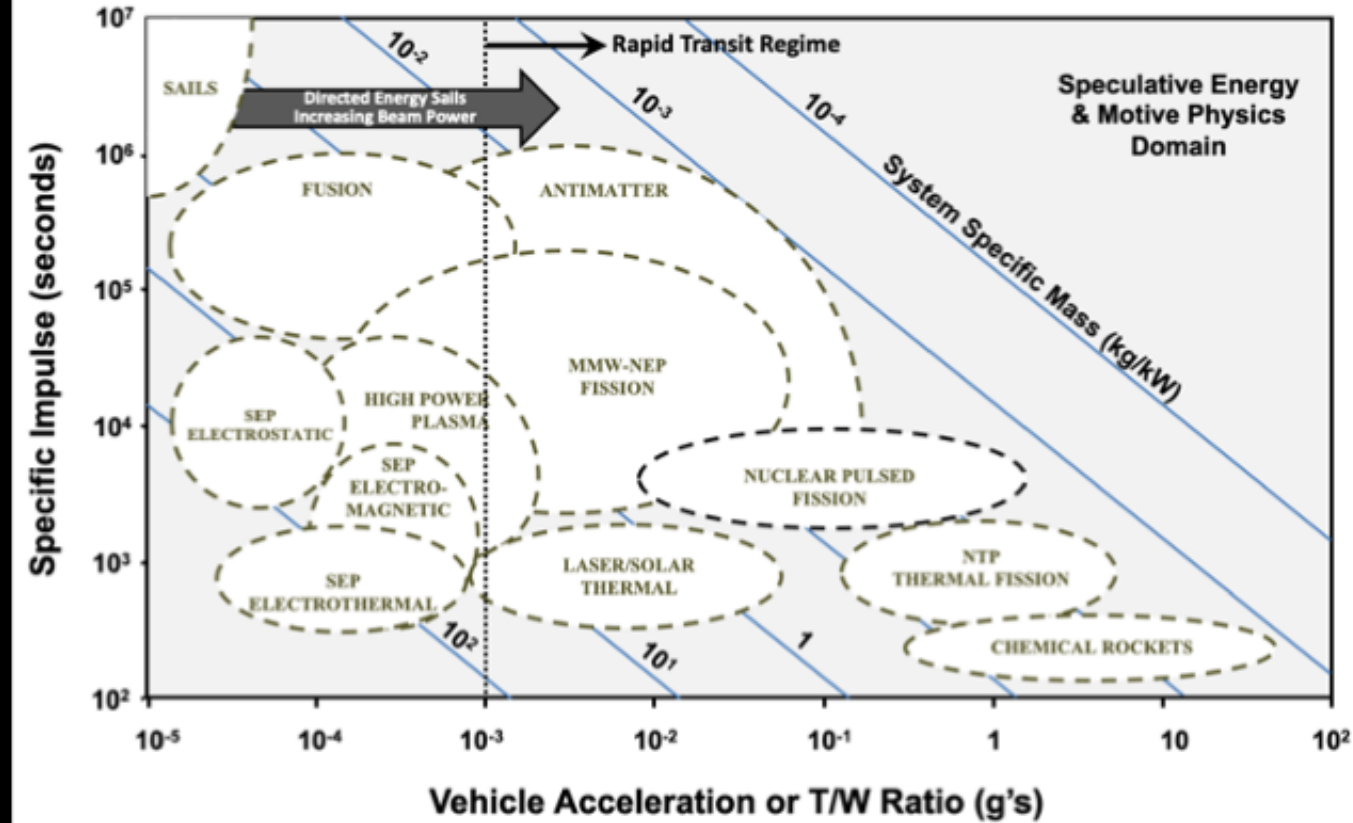
AEP R&D Challenges:

- Complex & Costly
- Long Learning Curves
- High Failure Rates

AEP Capability Goals:

- $\alpha \leq 5$ kg/kW
- Acceleration ≥ 0.006 g's
- High Isp $\gg 1000$ s

The Advanced Propulsion Landscape

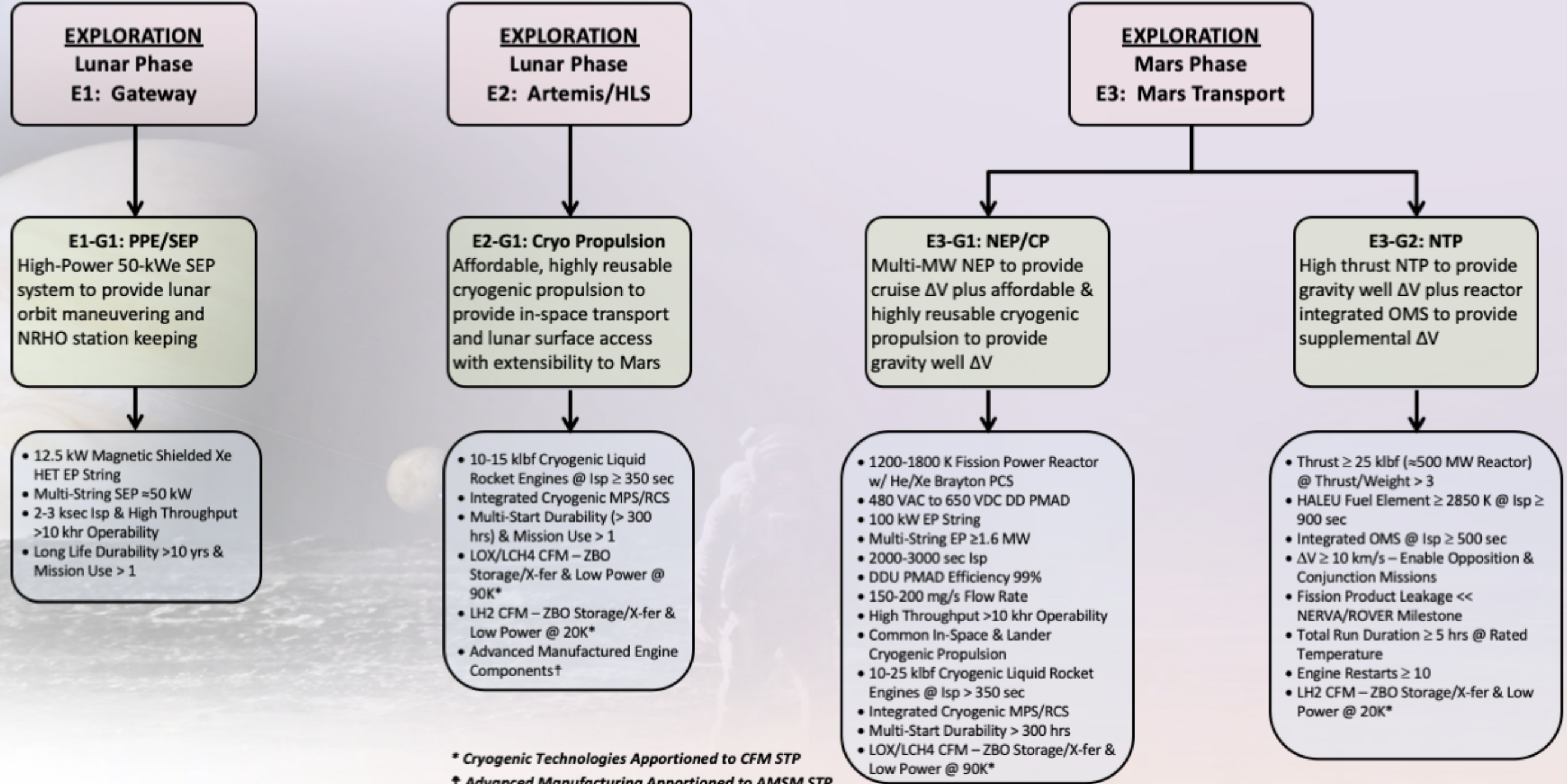


EXPLORATION ARCHITECTURE GAP INDICES

Quantifiable Capabilities Trace



ARCHITECTURE
CAPABILITY OUTCOMES
& TECHNICAL GAPS
QUANTIFIABLE
TECH CHALLENGES



* Cryogenic Technologies Apportioned to CFM STP

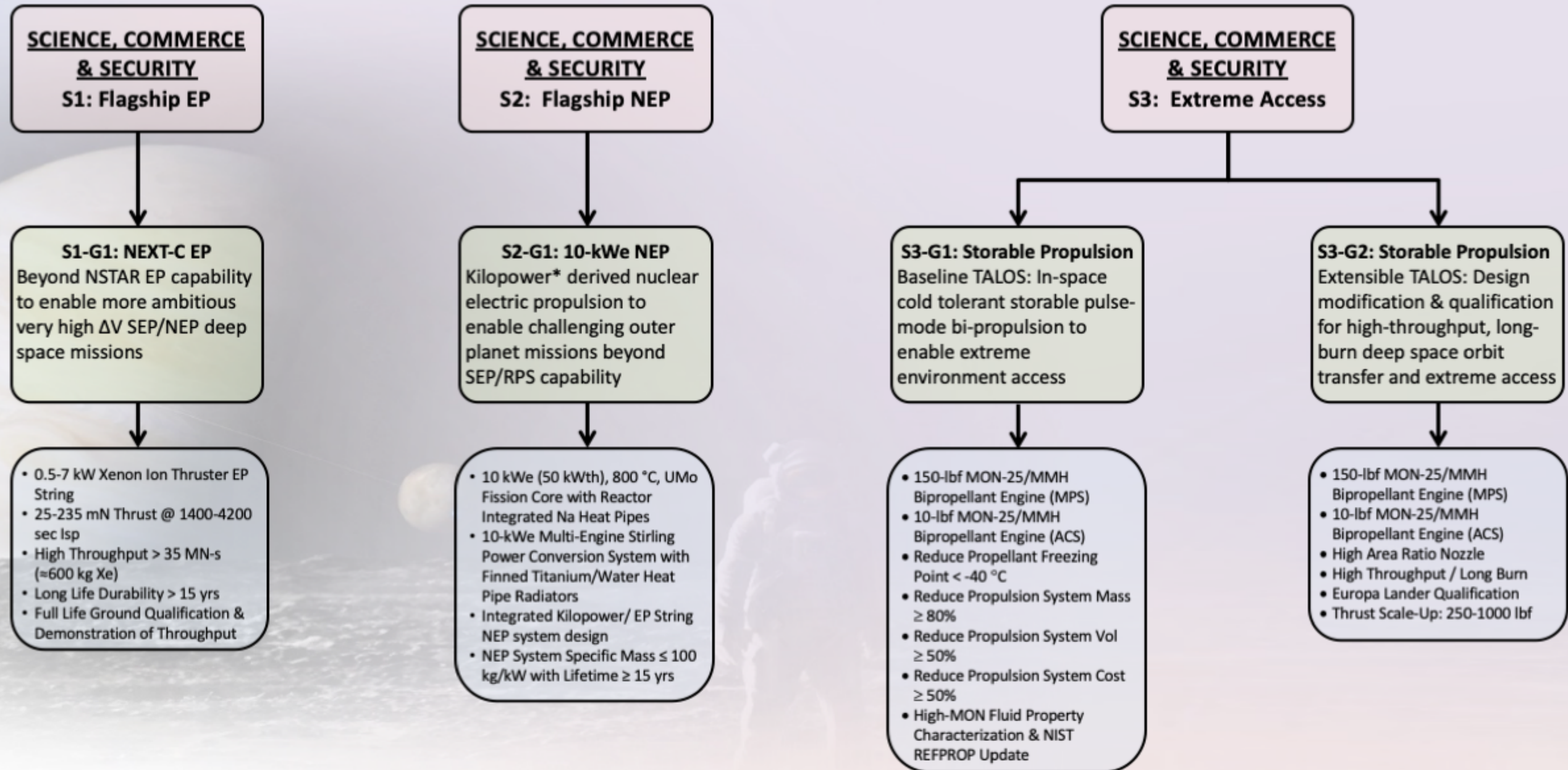
† Advanced Manufacturing Apportioned to AMSM STP

SCIENCE, COMMERCE & SECURITY ARCHITECTURE GAP INDICES

Quantifiable Capabilities Trace



ARCHITECTURE
CAPABILITY OUTCOMES
& TECHNICAL GAPS
QUANTIFIABLE
TECH CHALLENGES



* KiloPower Technology Apportioned to Advanced Power STP

SCIENCE, COMMERCE & SECURITY ARCHITECTURE GAP INDICES

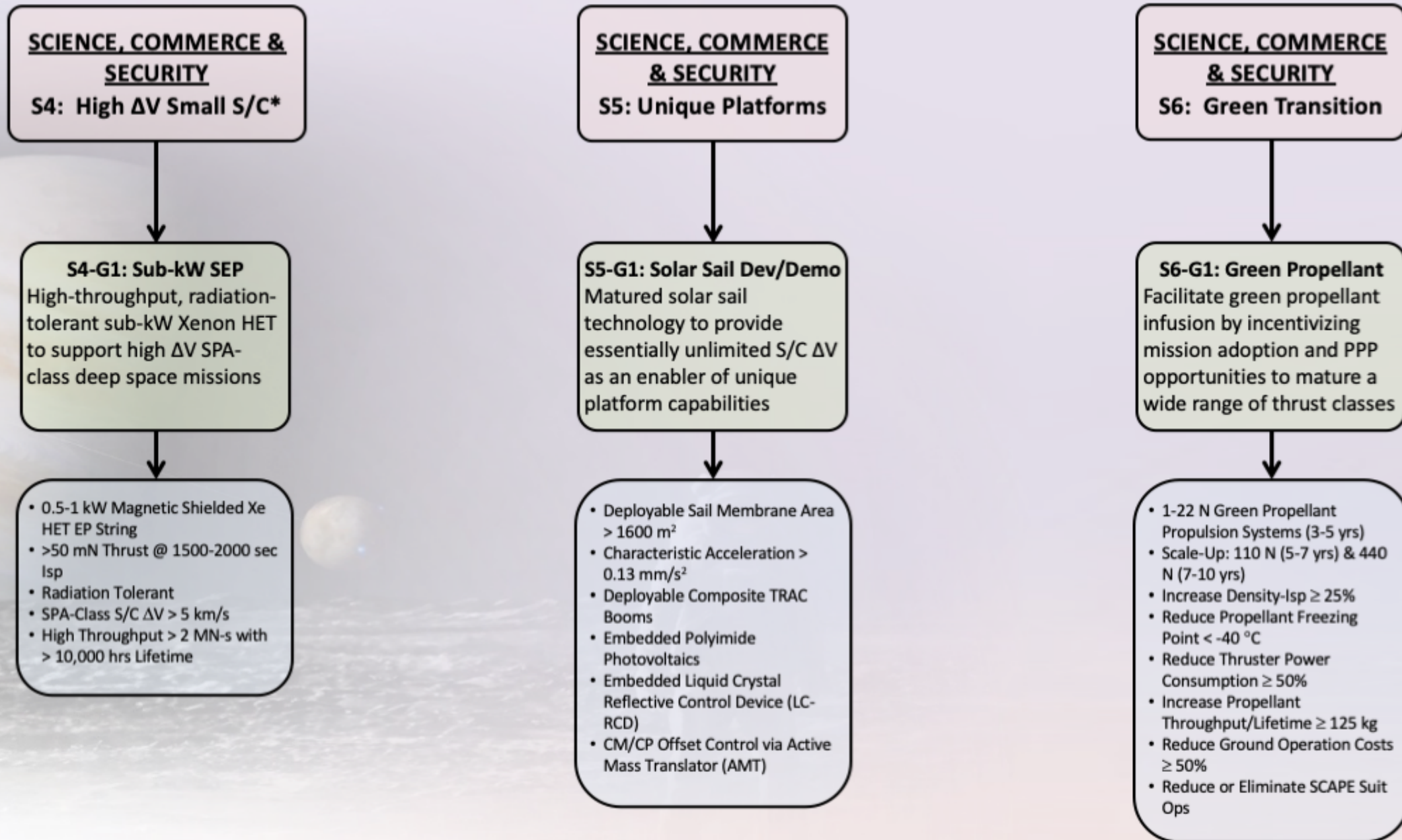
Quantifiable Capabilities Trace



ARCHITECTURE

CAPABILITY OUTCOMES
& TECHNICAL GAPS

QUANTIFIABLE
TECH CHALLENGES



* Sub-kW SEP Apportioned to Small Spacecraft Technologies STP

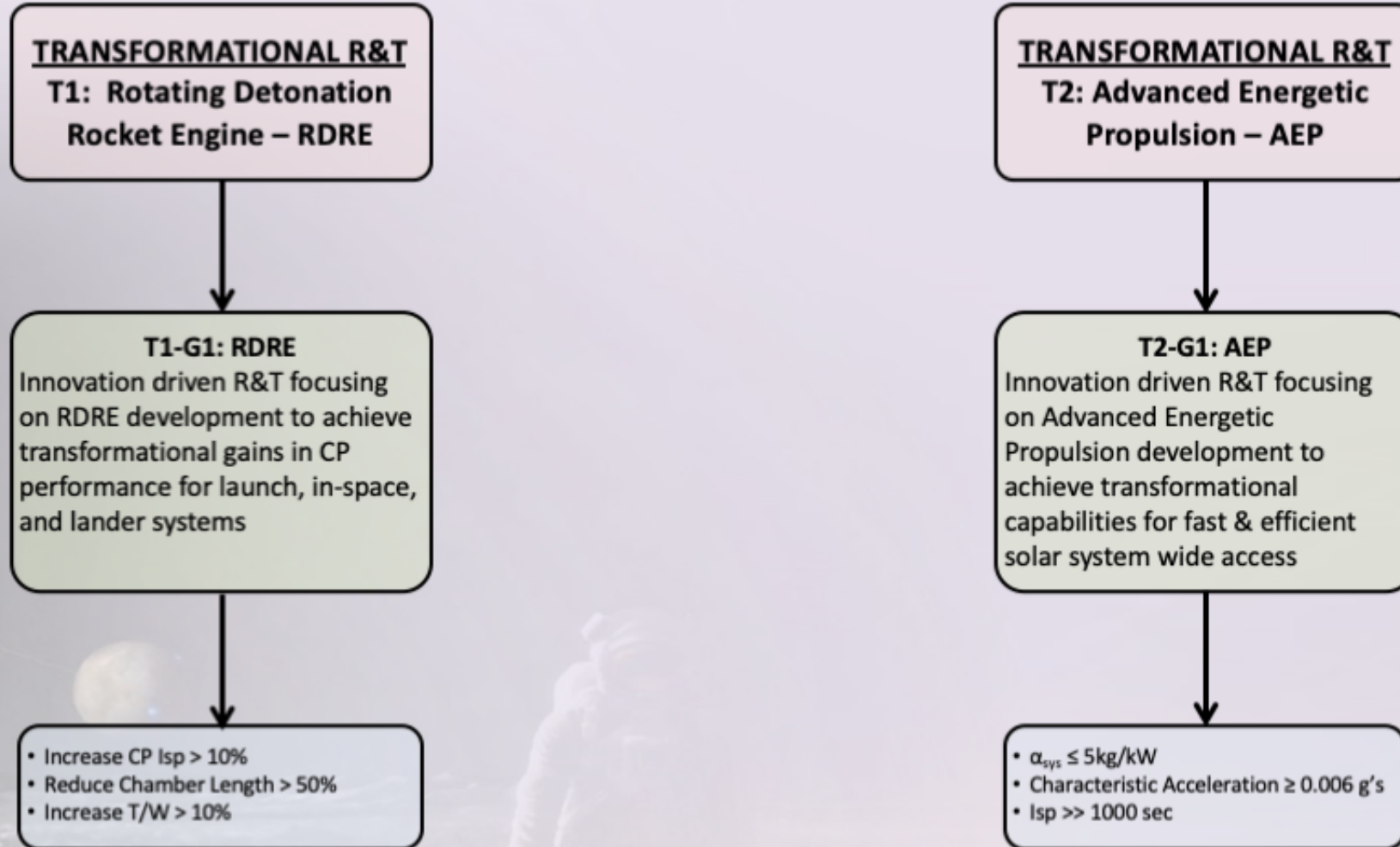


TRANSFORMATIONAL PUSH TECHNOLOGIES

Quantifiable Capabilities Trace



ARCHITECTURE
CAPABILITY OUTCOMES
& TECHNICAL GAPS
TECH CHALLENGES

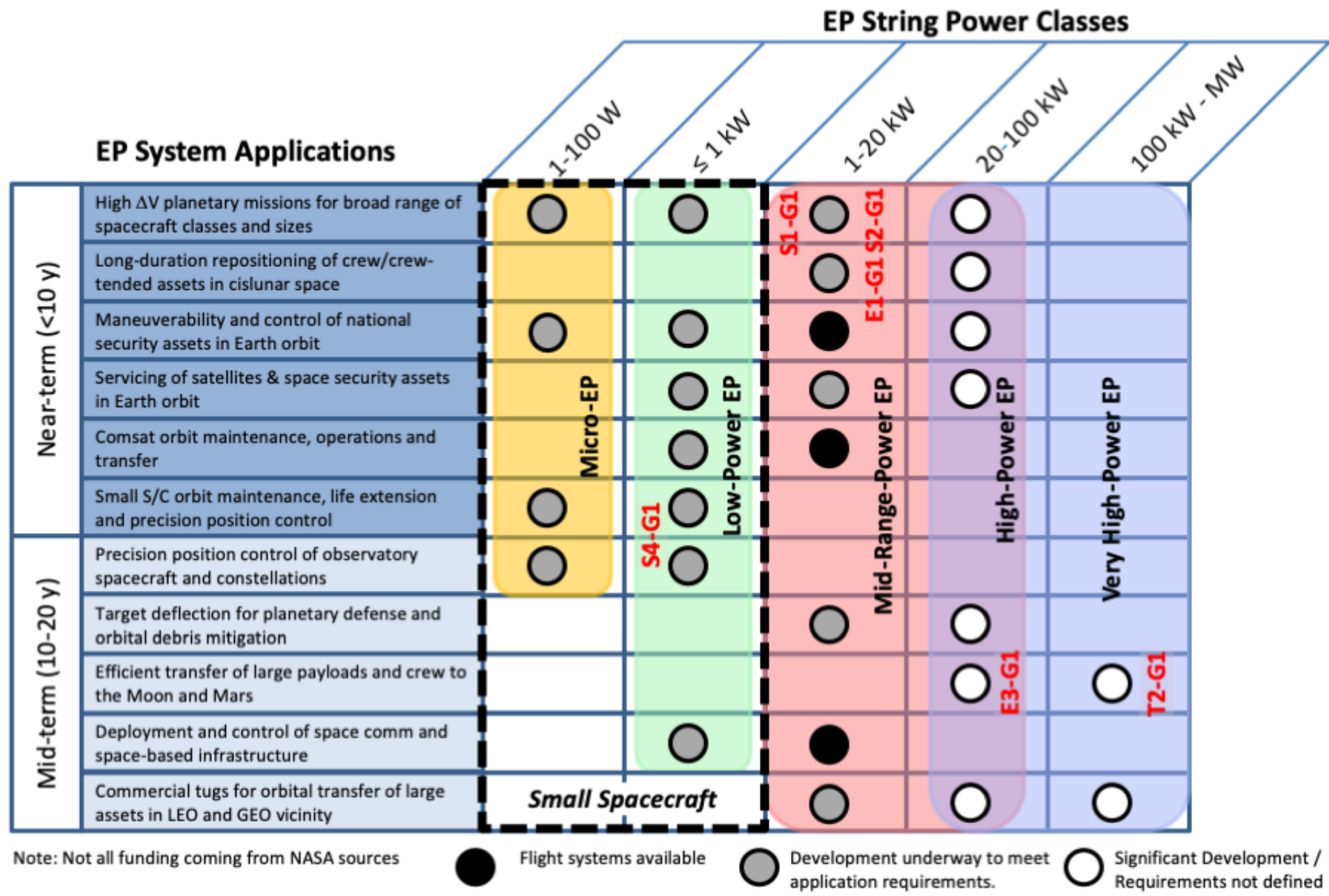


* Sub-kW SEP Apportioned to Small Spacecraft Technologies STP



ELECTRIC PROPULSION SYSTEMS

Historical Developments & Projected Capabilities

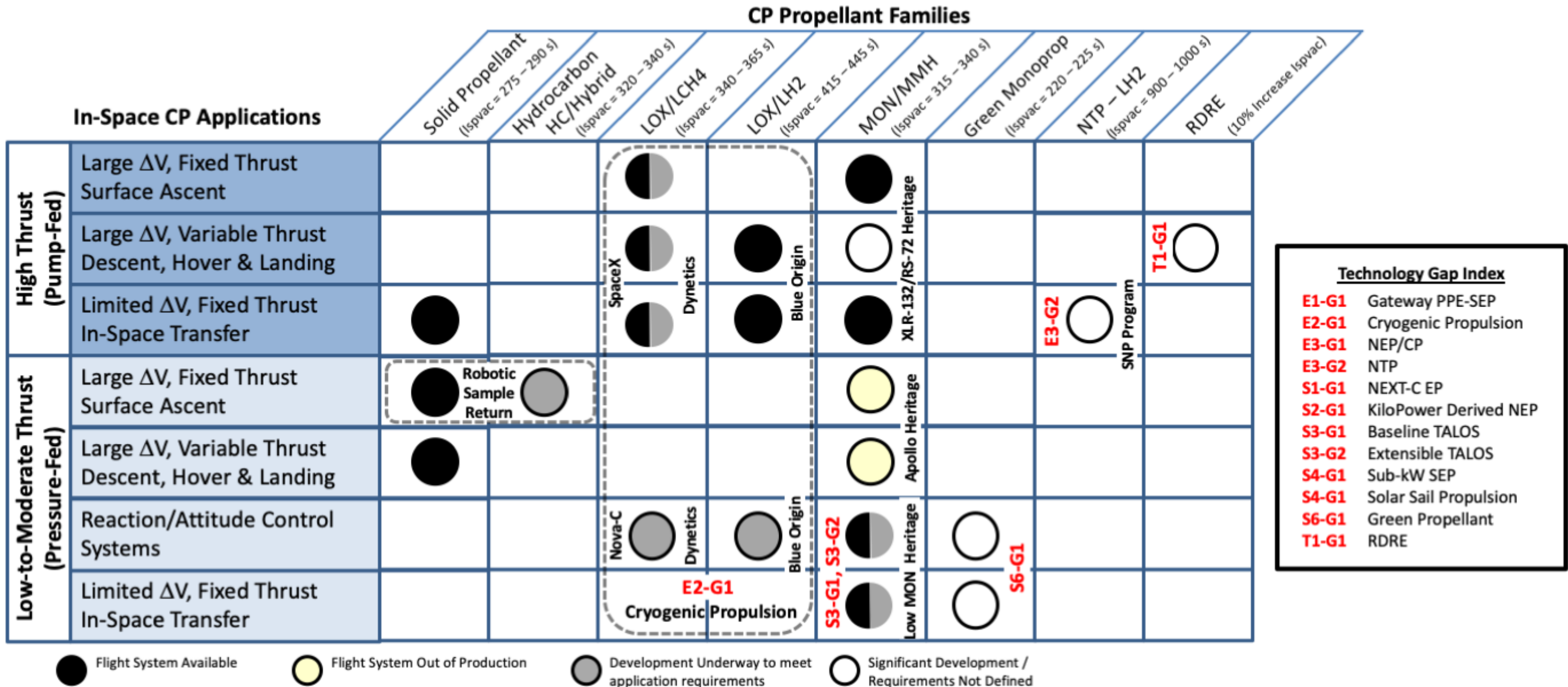


Technology Gap Index	
E1-G1	Gateway PPE-SEP
E2-G1	Cryogenic Propulsion
E3-G1	NEP/CP
E3-G2	NTP
S1-G1	NEXT-C EP
S2-G1	KiloPower Derived NEP
S3-G1	Baseline TALOS
S3-G2	Extensible TALOS
S4-G1	Sub-kW SEP
S4-G1	Solar Sail Propulsion
S6-G1	Green Propellant
T2-G1	AEP



CHEMICAL PROPULSION SYSTEMS

Historical Developments & Projected Capabilities

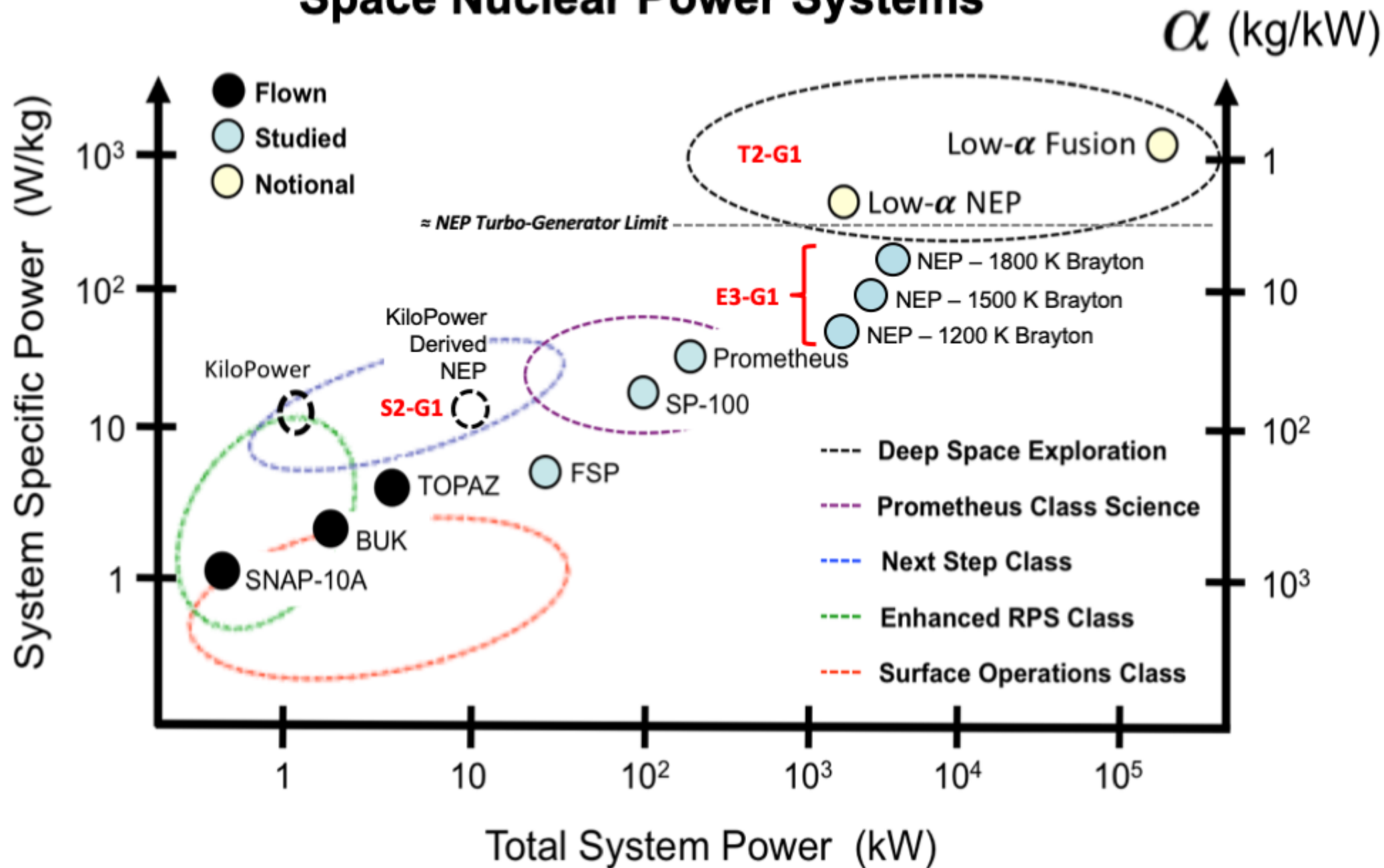




SPACE FISSION POWER SYSTEMS

Historical Developments & Projected Capabilities

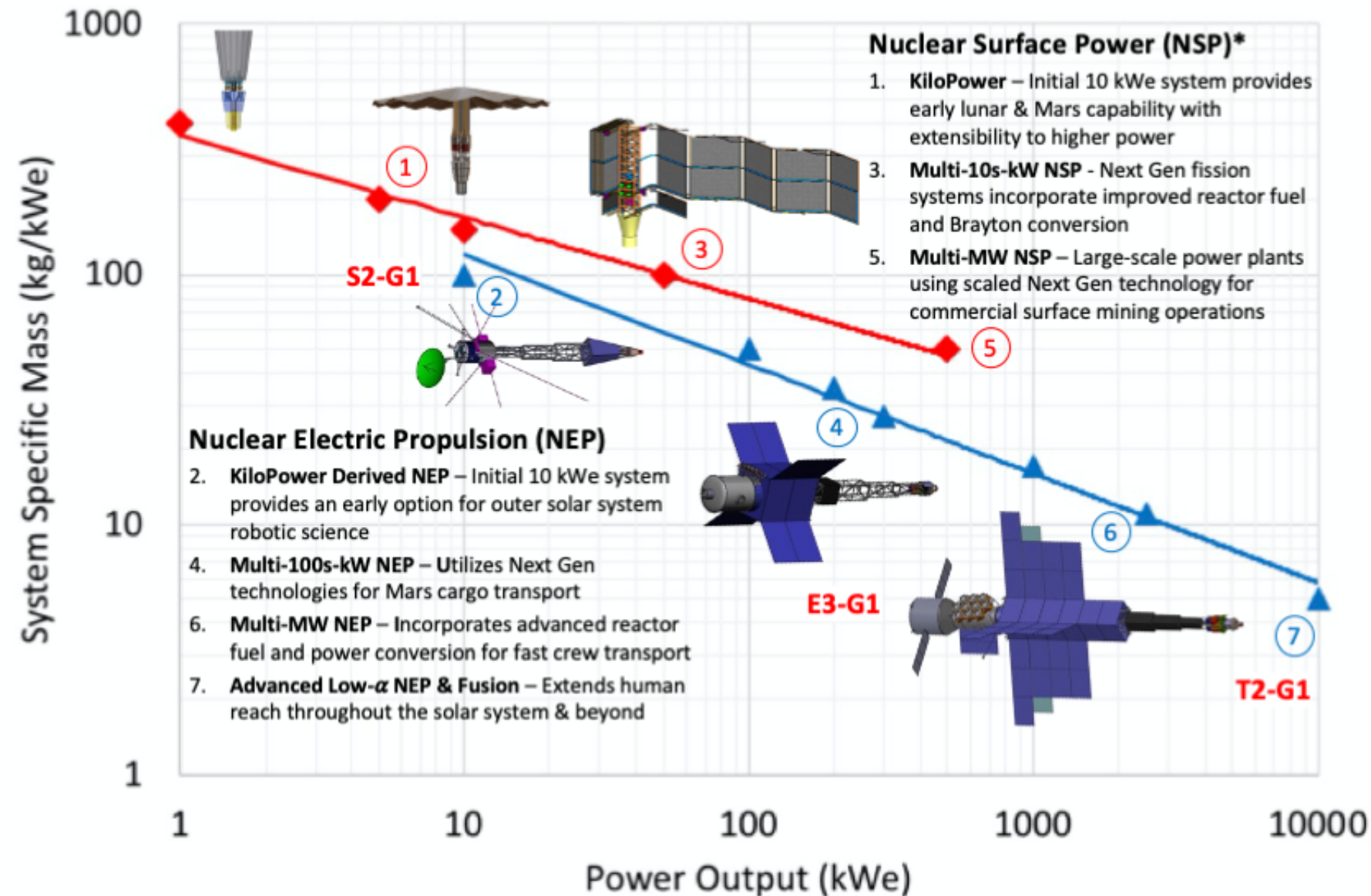
Space Nuclear Power Systems





SPACE FISSION POWER & PROPULSION SYSTEMS

Synergistic Development of NSP & NEP



* Apportioned to Advanced Power STP

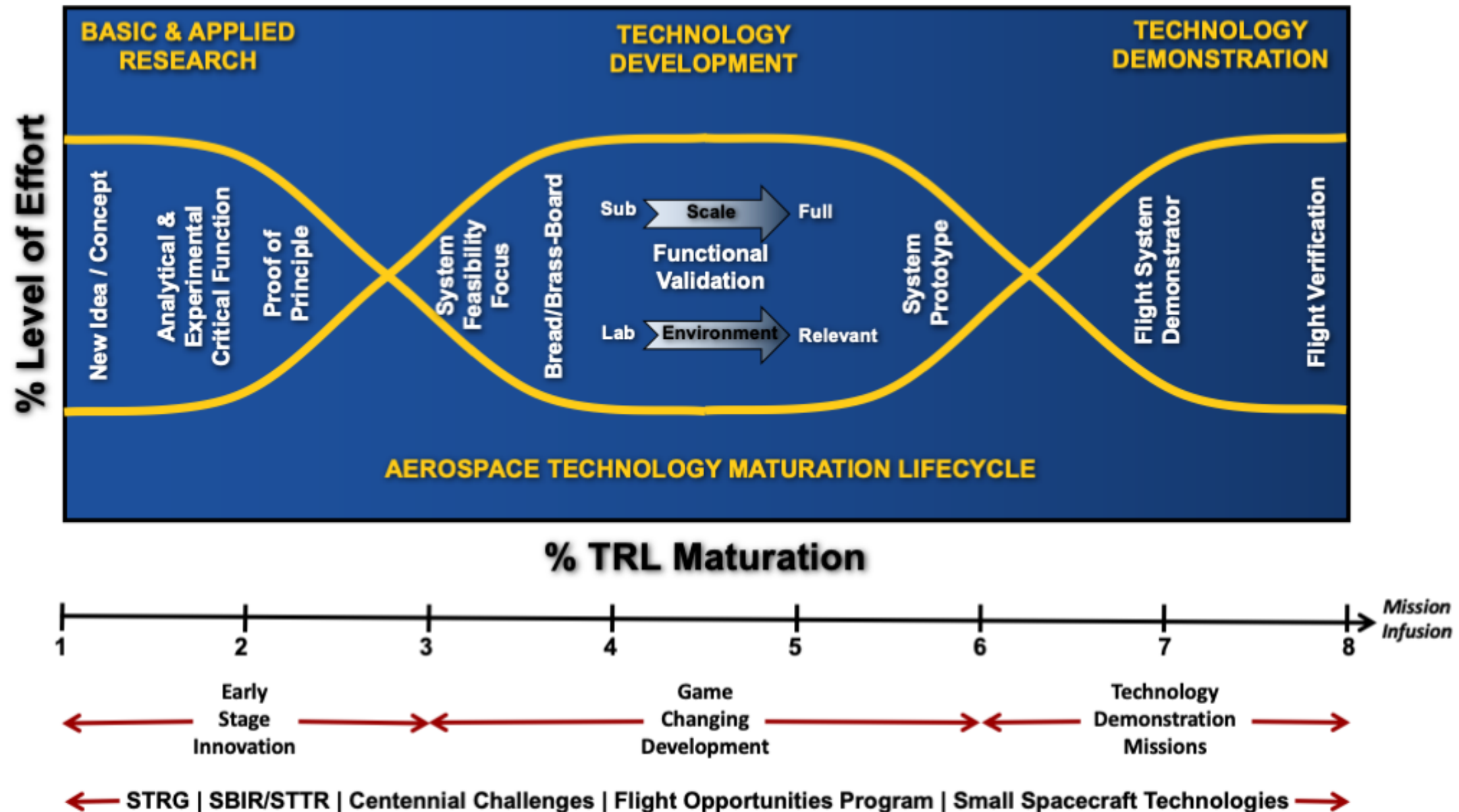


STRATEGIC CROSS-PROGRAM INTEGRATION

STMD Technology Lifecycle



DOUBLE HOURGLASS TRANSITION & INFUSION MODEL

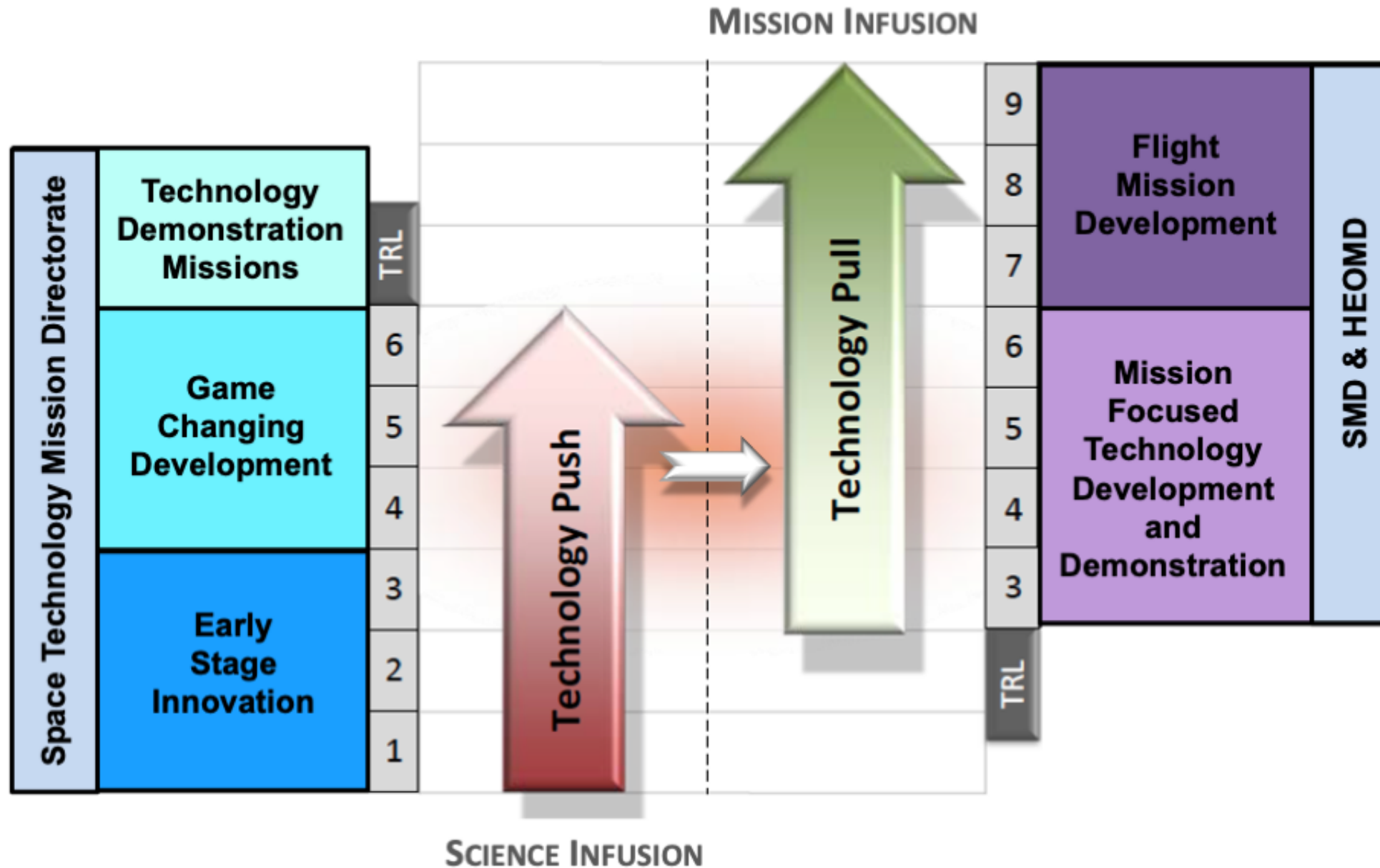


SPACE TECHNOLOGY MISSION DIRECTORATE PROGRAM PORTFOLIO



STRATEGIC CROSS-PROGRAM INTEGRATION

Space Technology Programmatic Flow



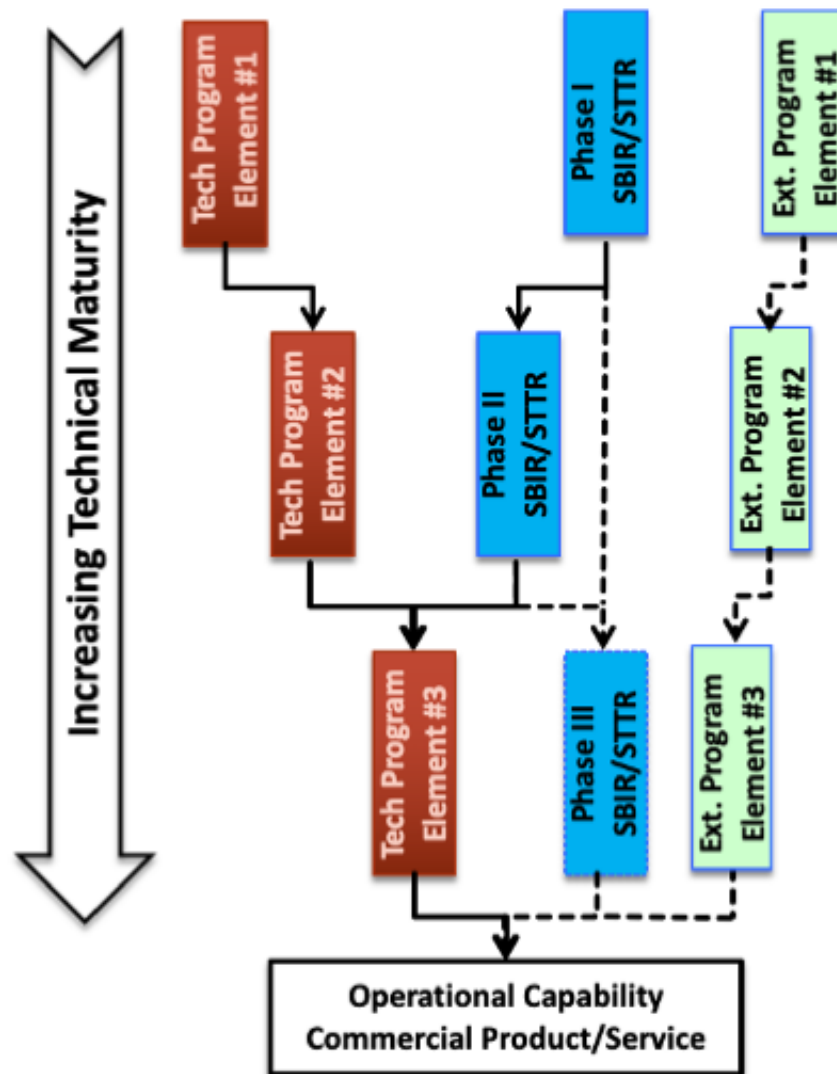


STRATEGIC CROSS-PROGRAM INTEGRATION

Integrated Program Elements



INTEGRATED PROGRAM ELEMENTS



CAPABILITY DEVELOPMENT COMMITMENT PARTITION

